CDM
50 West 14th Street, Suite 200
Helena, Montana 59601
tel: 406 441-1400
fax: 406 449-7725

Memorandum

To: *Brian Bartkowiak – DEQ*
Tom Mostad – NRDP

Copies: *Karin Boyd – AGI*
Tom Parker – Geum
Mike Hatten – TetraTech

From: *Bill Bucher – CDM*

Date: *December 21, 2011*

Re: *Revised Bank Toe Material Sizing For Phase 1 Preliminary Design Report, Clark Fork River Operable Unit*

At your request and based on comments received from peer reviewers (Pioneer Technical Services and River Design Group), I have revisited the channel bed and bank toe material sizing for the draft Phase 1 Preliminary Design Plan for the Clark Fork River. This memorandum proposes changes in the sizing of the bed toe material resulting from this reanalysis.

Some of the confusion on what was intended in regard to bank toe material sizing stems from the Design Criteria memorandum in Appendix A, which presented a first look at shear stresses at critical locations in Phase 1. This analysis, which was undertaken in 2010, was performed on the existing channel before the inset floodplain concept was developed, and, as a result, the information in Appendix A does not match more recent analysis based on the inset floodplain that was developed in 2011. In addition, no attempt was made to size bank toe material based on the 2010 shear stress estimates. In this memo I expand the analysis of shear stress and bank toe sizing that was presented in Section 4.4.2 of the draft Preliminary Design Plan to include more potentially problematic locations in Phase 1 and add a correction factor for bend radius at those locations on the outside of bends.

Channel Bed Materials

Before addressing the bed toe material sizing issue, it is instructive to review the mobility of the channel bed materials in the Phase 1 reach. The coarse fraction of existing channel bed materials, which will generally remain in place after remediation, appears to be fairly immobile under current hydrology based on observed embeddedness and lack of observable channel changes in Phase 1. Pebble counts were conducted on riffles in Phase 1 by AGI and CDM in 2009. The median particle diameter (d_{50}) for three measured riffles in Phase 1 below Warm

Springs Creek confluence was 1.63 inches and the d_{84} was 2.8 inches (CDM and AGI, 2010). In the Phase 1 Preliminary Design Report (PDP) (CDM *et al.*, 2011), the design criteria for channel stability was chosen to ensure bank (and presumably channel) stability under the 10-year peak flow event. HEC-RAS was used to calculate channel velocities and shear stresses at the measured cross sections for the 10-year flow (921 cfs above Warm Springs Creek confluence, 1094 cfs below). The model output for Phase 1 is attached. A selection of the surveyed cross sections was used to calculate the conditions for incipient motion of the bed under this flow. The sections were selected based on high total shear stress on the channel (which corresponded well with high grain shear stress), small bend radii and clearly failing banks. The last two selection criteria are more important for the bed toe analysis. The seven selected sections included those identified in the 2010 analysis presented in Appendix A of CDM *et al.* (2011).

Table 1 presents the results of the analysis. The shear stress was partitioned using Strickler's method as developed by Wilcock *et al.* (2006) modified for English units. These values are presented as "Grain Shear" in Table 1, and fall within reasonable values when related to total shear. Shields equation was used to estimate the median particle size that corresponds with incipient motion. A value of 0.030 for the dimensionless Shields coefficient was selected based on more current research on coarse grained systems than the previously used coefficient (0.047). Mueller *et al.* (2005) state that the Shields coefficient is typically 0.025 to 0.035 for gravel-bed rivers with slopes in the range 0.001 to 0.006. The slope of the Clark Fork River in Phase 1 varies from 0.002 to 0.003 so a midpoint of 0.030 appears appropriate for the Shields coefficient. Using the Shields equation, the values of "Critical d_{50}" were calculated. For unimodal gravel distributions, this is the characteristic size at which incipient motion on the bed would occur at the modeled flow.

Table 1. 10-Year Event Critical Shear Stress Analysis for Channel Bed, Phase 1.

Cross-section	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Grain Shear (lb/sq ft)	Shear Chan (lb/sq ft)	Hyd. Radius (ft)	Critical d_{50} (in)
XS36	0.0038	5.27	0.45	0.71	2.98	1.74
XS39	0.0028	5.07	0.39	0.62	3.49	1.52
XS40	0.0041	5.01	0.42	0.67	2.64	1.63
XS42	0.0022	4.09	0.27	0.36	2.57	1.04
XS47	0.0024	3.58	0.22	0.29	1.96	0.86
XS53	0.0028	4.38	0.31	0.50	2.81	1.22
XS57	0.0004	1.63	0.04	0.07	2.96	0.17

Notes: D_{84} for channel bed material is 2.8 in.
Shield's Coefficient = 0.030

The largest calculated d_{50} for the sections in Table 1 is 1.74 in. at cross section 36, and the second largest is 1.63 in. at cross section 40. Both of these sections are located at riffles. The average d_{50} of three riffles measured by AGI and CDM is 1.63 in. A comparison of the average d_{50} (1.63 in) to the calculated critical d_{50} values in Table 1 indicates that only three cross sections (XS36, XS 39, and XS40) are in the range of d_{50} mobilization at a 10-year event. This lack of coarse sediment mobility reflects the combined conditions of low channel slope, impacted hydrology, and reduced sediment inputs due to Warm Springs Ponds. Smith *et al*. (1998) concluded that the coarse bed material on the upper Clark Fork River represents a largely immobile armor layer that formed as the river incised in response to beaver dam removal and flood events. Our field observations support this interpretation, especially in light of reduced sediment supply due to Warm Springs Ponds.

This year, however, large volumes of coarse sediment were moved through the system; particles up to several inches in diameter were mobilized. These coarse gravels were presumably delivered primarily by Warm Springs Creek. However, this event significantly exceeded the 10-year design criteria threshold. In 2011, the maximum mean daily flow measured at Galen was 1390 cfs on June 13. This is almost a 50 year event (Q50 instantaneous peak is 1415cfs). The 10-year event of 1,090 cfs was exceeded for 21 days (mean daily flow) between June 8 and July 2, and the 25 year event of 1,286 cfs was exceeded 6 days. Thus, if this year is used as a guideline for sizing a rock toe, the long-term deformability of the system could be compromised.

Bank Toe Material

The previous calculation for channel material size has been extended to address the required bank toe material size. The additional consideration for bank toe material sizing is that shear stresses increase on the outside of bends due to the deflection of the flow by the bank. Table 2 accounts for this effect by developing the ratio of Radius to Width (R/W) for the sections, and applying the coefficient determined by the U.S. Soil Conservation Service (1977) to the shear on the grains. This increases the d_{50} for those sections located at bends as shown in the "Critical D_{50}" column. Note that the grain shear stress has also increased due to the dependence of grain shear stress on the size of larger (d_{84} in this case) particle sizes that are anticipated for the manufactured bank toe material.

Table 2 shows that the highest corrected shear and largest critical d_{50} size (2.08 in.) occurs on a bend at cross section 42. The second largest shear occurs on a straight section at cross section 36 (1.95 in.). Using a median size of about 2 inches, the bed toe material can be sized to provide the desired degree of bank toe protection; i.e., stable up to the 10-year flow event. Figure 1 shows a proposed gradation for bank toe material for locations where a bank toe needs to be constructed. The average gradation has a d_{50} of 2 inches, a d_{84} of 4.5 inches, and d_{max} of 9 inches.

Discussion

The existing bank toe material in Phase 1was investigated during investigations by Tetra Tech in 2009 (Tetra Tech, 2010). Although test pits were not located near all cross sections, where a test pit was close to a section the material type and the sampled interval are noted in "Toe Material." The proposed bank remediation type is also noted. Type 2 banks are single lift installations where some woody vegetation in good condition is available at the appropriate height in the existing bank. These locations are not proposed for bank toe installation. Type 3 banks are planned where insufficient adequate woody vegetation is available in the bank, and

Table 2. 10-Year Event Critical Shear Stress Analysis for Bank Toes

Cross-section	Design Sta. (ft)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Grain Shear (lb/sq ft)	Shear Chan (lb/sq ft)	Hyd. Radius (ft)	R/W	R/W Corr.	Corr. Shear (lb/sq ft)	Critical D_{50} (in)	Toe Material	Remediation Bank Type
XS36	82+00	0.0038	5.27	0.50	0.71	2.98	Straight	1	0.50	1.95	GP 60-72" LB	Type 3 LB
XS39	87+10	0.0028	5.07	0.44	0.62	3.49	Straight	1	0.44	1.71	NA	Type 2 LB
XS40	88+30	0.0041	5.01	0.47	0.67	2.64	Straight	1	0.47	1.84	NA	Type 2 RB
XS42	92+10	0.0022	4.09	0.30	0.36	2.57	3.4	1.78	0.53	2.08	SM 66-80"	Type 3 RB
XS47	101+00	0.0024	3.58	0.25	0.29	1.96	2.7	1.89	0.47	1.84	SM 60-80"	Type 2&3 RB
XS53	111+10	0.0028	4.38	0.35	0.50	2.81	Straight	1	0.35	1.38	SP 54-78"	Type 2
XS57	119+10	0.0004	1.63	0.05	0.07	2.96	2	2.00	0.10	0.38	SW 48-72" RB	Type 3 RB

Notes: d_{84} is 4.5 in. for bank toe gradation.
Shields Coefficient is 0.030

NA	Not Available
RB	Right Bank
LB	Left Bank
GP	Poorly sorted gravel
SM	Sandy silt
SP	Poorly sorted sand
SW	Well sorted sand
R/W	Radius/Width for bends
R/W Corr.	From U.S. Soil Conservation Service, 1977.

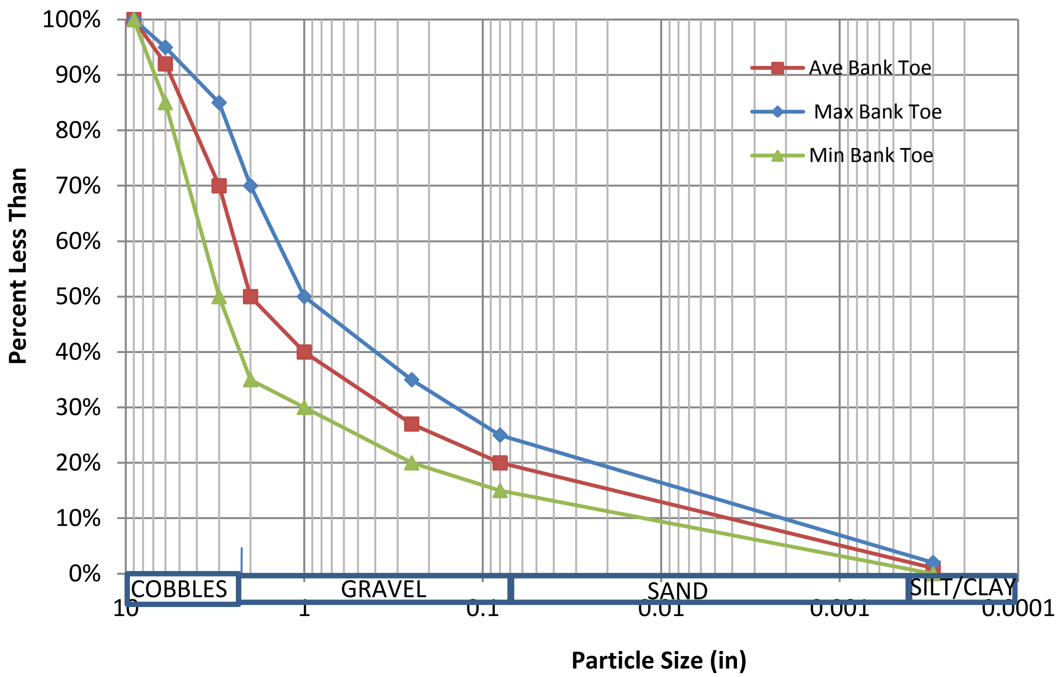

Figure 1. Proposed Bank Toe Gradation

a bank toe would need to be installed if properly sized alluvium is not present. For most of these locations, a bank toe should be installed. For sites requiring Type 3 banks other than those listed in Table 2 and where alluvial material is in place at the correct depth, the criteria for adequate material size can be the proposed floodplain material sizing (d_{50} = 1.2 inches). This is justified by the lower shear stresses at these locations. However, for those sites listed in Table 2 where Type 3 banks will be placed, the new bank toe sizing (d_{50} = 2 inches) should be used. If the cross section 36 bank toe material, which is a gravel, meets the new sizing (d_{50} = 2 inches), it can be left in place. Otherwise it should be rebuilt with the new bank toe material size. All other Type 3 bank locations in Table 2 (cross sections 42, 47, and 57) should be rebuilt with the new bank toe size because their current toes are inadequate being composed of sand or silt material.

Table 2 hints at a potentially expected correlation between failing banks and inadequate bank toes since all banks requiring Type 3 construction except section 36 have sand or silt toes. However, note that cross section 53, which has a sand toe but is not on a bend, supports desirable woody vegetation. Another interesting case is cross section 57, the sharpest bend in Phase 1 and the location of a highly erosive bank. At this location, although shear stresses are quite low, the bank is failing because of its sandy toe and lack of bank vegetation.

Please review the proposed bank toe gradation. If it is acceptable to the design team and the agencies, CDM proposes that we implement this bank toe gradation in the next design package for Phase 1. We understand that further adjustment to this and other proposed gradations may need to be made once sources for the alluvial material are designated.

References

CDM and AGI, 2010. Clark Fork River Operable Unit, Milltown Reservoir/Clark Fork River NPL Site, Powell, Deer Lodge and Granite Counties, Montana. Part 2, Geomorphic, Hydrologic, and Hydraulic Investigation for Phase 1 Remedial Design/Remedial Action. April 2010.

CDM, Tetra Tech, Geum Environmental Consulting, Inc., and Applied Geomorphology, Inc., 2011. Draft Phase 1 Preliminary Design Plan. Clark Fork River Operable Unit, Milltown Reservoir/Clark Fork River NPL Site, Powell, Deer Lodge and Granite Counties, Montana. May 15, 2011.

Mueller, E.R., J. Pitlick, and J.M. Nelson, 2005. Variation in the reference Shields stress for bed load transport in gravel-bed streams and rivers. Water Resources Research, Vol. 41. WW04006.

Smith, J.D., J.H. Lambing, D.A. Nimick, C.Parrett, M. Ramey, and W. Schafer, 1998. Geomorphology, flood-plain tailings, and metal transport in the Upper Clark Fork Valley, Montana: USGS Water Resources Investigations Report 98-4170, 56p.

Tetra Tech, 2010. Clark Fork River Operable Unit, Milltown Reservoir/Clark fork River NPL Site, Powell, Deer Lodge and Granite Counties, Montana. Part 1, Data Summary Report – Reach A, Phase 1.

Wilcock, P., J. Pitlick and Y. Cui, 2006. Sediment Transport Primer and BAGS User’s Manual, Part 1: Sediment Transport Primer. Draft – February 26, 2006. Produced by USDA Forest Service, Washington, D.C.

ATTACHMENT
SUMMARY OF ENERGY GRADE , VELOCITIES AND SHEAR STRESSES IN PHASE 1
December 16, 2011

	Q Total	E.G. Slope	Vel Chnl	Vel Left	Vel Right	Shear Chan	Shear LOB	Shear ROB
Section	cfs	ft/ft	ft/s	ft/s	ft/s	lb/ft^2	lb/ft^2	lb/ft^2
XS 14	921	0.0031	5.27	1.24		0.67	0.05	
XS 15	921	0.0011	3.35	1.14	0.67	0.27	0.06	0.03
XS 16	921	0.0007	2.44	0.88	0.26	0.14	0.03	0.01
XS 17	921	0.0020	4.33	1.36	1.17	0.45	0.08	0.07
XS 18	921	0.0002	1.36	0.67	0.72	0.04	0.02	0.02
XS 19	921	0.0001	1.29	0.53	0.49	0.03	0.01	0.01
XS 20	921	0.0002	1.35	0.48	0.65	0.04	0.01	0.02
XS 21	1094	0.0004	1.45	1.20	0.91	0.06	0.05	0.03
XS 22	1094	0.0004	1.97	0.72	0.83	0.09	0.02	0.03
XS 23	1094	0.0003	2.08	0.99	0.78	0.09	0.04	0.03
XS 24	1094	0.0007	3.17	0.87	1.26	0.21	0.04	0.06
	1094	0.0013	3.60			0.31		
	Bridge							
	1094	0.0018	4.08			0.40		
XS 25	1094	0.0008	3.32	1.95	0.73	0.18	0.04	0.05
XS 25A	1094	0.0015	3.97	1.09	1.36	0.37	0.06	0.09
XS 25B	1094	0.0016	3.88	1.00	1.12	0.36	0.06	0.08
XS26	1094	0.0021	4.16	1.17	1.47	0.43	0.07	0.10
XS27	1094	0.0013	3.71	0.82	1.20	0.32	0.04	0.07
XS28	1094	0.0009	2.64	1.68	1.14	0.17	0.08	0.06
XS29	1094	0.0012	3.74	1.28	1.15	0.32	0.07	0.06
XS30	1094	0.0019	4.56	1.35	1.36	0.48	0.09	0.09
XS31	1094	0.0010	2.98	0.82	1.02	0.21	0.04	0.05
XS32	1094	0.0008	2.72	0.75	0.89	0.15	0.03	0.04
XS33	1094	0.0008	2.87	0.92	0.78	0.19	0.04	0.03
XS34	1094	0.0024	4.54	1.13	1.18	0.50	0.04	0.08
XS35	1094	0.0019	4.64	1.19	0.94	0.49	0.07	0.07
XS36	1094	0.0038	5.27	1.65	2.68	0.71	0.15	0.26
XS37	1094	0.0015	3.71	0.69	2.08	0.33	0.03	0.13
XS38	1094	0.0032	3.97	1.59	0.71	0.44	0.13	0.04
XS39	1094	0.0028	5.07	1.27	1.10	0.62	0.09	0.07
XS40	1094	0.0041	5.01	1.20	1.42	0.67	0.09	0.12
XS41	1094	0.0018	2.92	0.43	0.35	0.23	0.02	0.01
XS42	1094	0.0022	4.09	1.05	1.12	0.36	0.06	0.07
XS43	1094	0.0015	3.11	0.74	1.05	0.26	0.03	0.06
XS44	1094	0.0016	3.26	1.23	1.08	0.28	0.08	0.06
XS45	1094	0.0018	4.27	1.41	0.91	0.43	0.09	0.05
XS46	1094	0.0019	4.27	0.61	0.87	0.39	0.03	0.05
XS47	1094	0.0024	3.58	0.97	0.55	0.29	0.05	0.03

	Q Total	E.G. Slope	Vel Chnl	Vel Left	Vel Right	Shear Chan	Shear LOB	Shear ROB
Section	**cfs**	**ft/ft**	**ft/s**	**ft/s**	**ft/s**	**lb/ft^2**	**lb/ft^2**	**lb/ft^2**
XS48	1094	0.0011	3.16	0.69	0.89	0.24	0.03	0.04
XS49	1094	0.0011	3.03	0.77	0.72	0.22	0.03	0.03
XS50	1094	0.0011	3.23	1.05	0.90	0.25	0.05	0.04
XS51	1094	0.0006	2.72	0.55	0.55	0.16	0.02	0.02
XS52	1094	0.0011	3.28	0.30	0.66	0.19	0.01	0.03
XS53	1094	0.0028	4.38	1.41	1.10	0.50	0.11	0.07
XS54	1094	0.0028	4.44	1.46	0.65	0.51	0.11	0.03
XS55	1094	0.0029	4.57	1.46	0.50	0.53	0.11	0.02
XS56	1094	0.0004	2.04	1.16	0.17	0.10	0.03	0.00
XS57	1094	0.0004	1.63	0.81	0.36	0.07	0.03	0.01
XS58	1094	0.0003	1.70	0.73	0.34	0.06	0.02	0.01
XS59	1094	0.0004	2.24	0.63	0.07	0.11	0.03	0.02
XS60	1094	0.0021	4.37	0.75	0.77	0.46	0.04	0.04
Average		**0.0015**	**3.39**	**1.02**	**0.91**	**0.30**	**0.05**	**0.05**
Maximum		**0.0041**	**5.27**	**1.95**	**2.68**	**0.71**	**0.15**	**0.26**